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Active Cell Balancing Technique for EV Batteries

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ABSTRACT

Various cell balancing techniques have been proposed to address mismatched cells in a series string. Dissipative balancing is simple and cost-effective but slow and inefficient, while capacitor balancing offers compactness and affordability with limited speed. Converter-based and runtime balancing techniques provide better balancing speed and efficiency. This study discusses a battery pack consisting of four cells and proposes an active cell balancing (ACB) model using a Buck-Boost converter. The proposed ACB method demonstrates faster balancing and lower power loss compared to passive balancing using switching shunt resistors, making it more suitable for lithium-ion battery-powered electric vehicles

Keywords: **Active Cell Balancing, Battery Management System, Buck-Boost Converter, Lithiumion Battery**

INTRODUCTION

Imbalance of cells in battery systems is very common and can arise from both internal and external sources. Internal sources include manufacturing variances in physical volume, variations in internal impedance, and differences in self-discharge rates. External sources mainly involve multi-rank pack protection ICs draining unequally from different series ranks in the pack. Additionally, thermal differences across the pack can also cause imbalance, as they lead to different self-discharge rates among the cells.

Balancing methods are generally classified into passive and active methods. The passive balancing method is mainly used for Lead-acid and Nickel-based batteries. These batteries can tolerate overcharge conditions without permanent cell damage. When overcharge is mild, the excess energy is released by increasing the cell body temperature. In cases of severe overcharge, the excess energy is released through gassing via the gassing valve built into the cells.

Overcharge balancing is a natural method for maintaining balance in a series string of such cells. However, it is only effective for a small number of series cells because balancing problems grow exponentially with the number of cells. Generally, passive balancing is a cost-effective solution for low-voltage Lead-acid and Nickel-based battery systems

RELATED WORK

The concept of active cell balancing was first introduced to overcome the limitations of passive balancing methods in battery management systems [1]. Inspired by the need for efficient energy redistribution among cells, active balancing methods aim to transfer excess charge from higher energy cells to lower energy cells rather than dissipating it as heat. In [2], switched capacitor methods were proposed, where capacitors are used as intermediate storage elements to transfer energy between cells.

This technique ensures energy conservation and improves the overall efficiency of the battery pack.Inductive-based active balancing methods, as proposed in [3], use inductors and transformers to transfer energy, allowing for faster balancing and supporting large battery systems. A multi-winding transformer approach introduced in [4] enables simultaneous balancing of multiple cells, thus reducing balancing time significantly. In [5], a distributed active balancing strategy was developed that uses power electronics to individually control the energy flow among cells, making the system scalable and adaptable to varying battery pack configurations. The authors in [6] have further optimized the energy transfer paths using advanced switching networks and intelligent control algorithms, enhancing both speed and efficiency of the balancing process.

METHODOLOGY

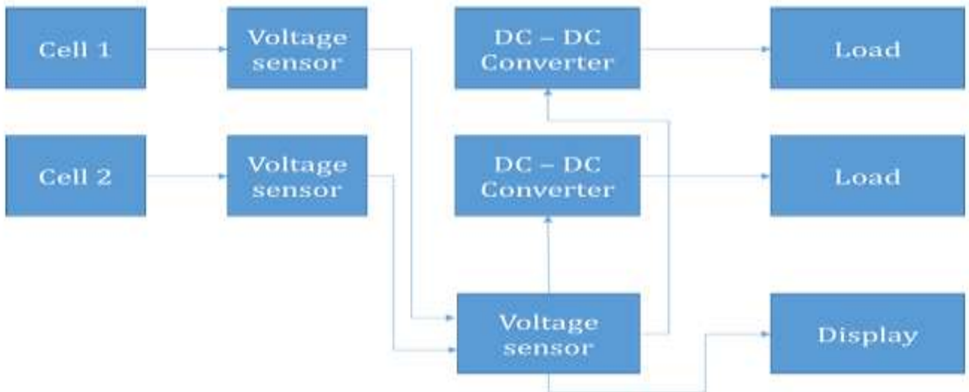

Fig.1 Block diagram of Active cell balancing technique for EV

The figure illustrates an active cell balancing technique used for electric vehicle (EV) batteries. In this method, individual cells, labelled as Cell 1 and Cell 2, are continuously monitored by voltage sensors to measure their respective voltages. The measured voltages are then supplied to DC-DC converters, which actively transfer energy from one cell to another or directly to the load, depending on the voltage levels. This energy transfer helps equalize the state of charge between the cells, improving the overall efficiency of the battery pack. After the energy transfer, another voltage sensor measures the output voltage to ensure proper balancing. The system also features a display unit that shows the real-time voltage readings for monitoring purposes. Active cell balancing, unlike passive balancing, redistributes energy rather than dissipating it as heat, leading to higher efficiency, better battery performance, and extended battery life, which are critical factors in the operation of electric vehicles.

SIMULATION MODEL OF ACTIVE CELL BALANCING

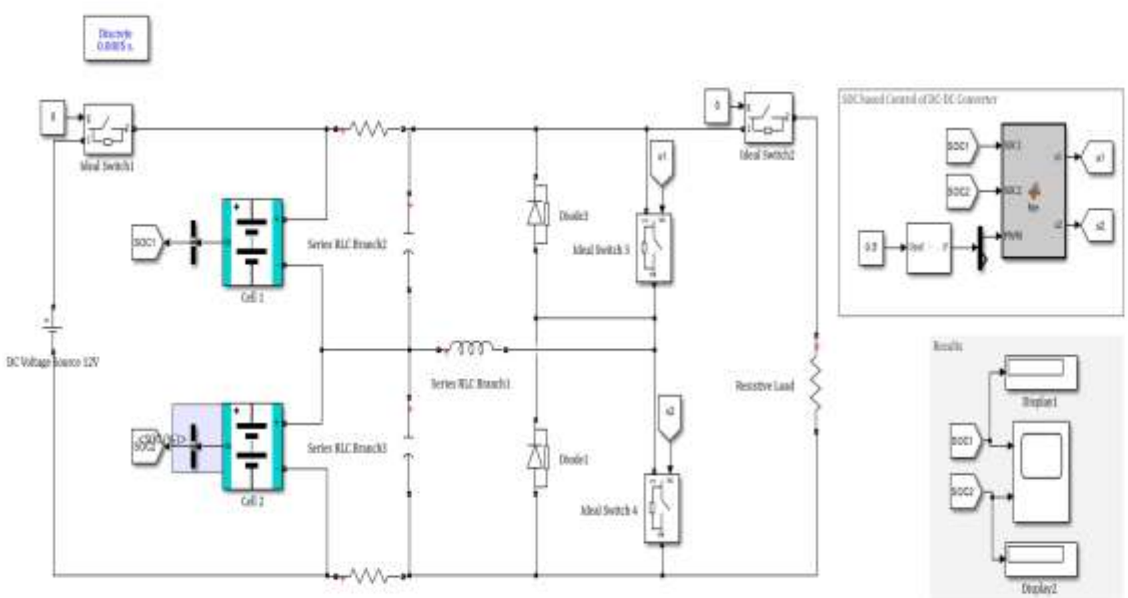

Fig.2 Simulation Active Cell Balancing Technique

The given Simulink model illustrates a State of Charge (SOC)-based control system for a DC-DC converter managing two battery cells. Each cell (Cell 1 and Cell 2) is connected through a Series RLC branch, which represents the internal impedance of the batteries. A 12V DC voltage source powers the system, and SOC measurements from both cells are used as feedback to regulate power flow. The SOC-based control block processes these inputs and generates control signals (s1 and s2) using pulse-width modulation (PWM). These signals operate Ideal Switches 1 and 2, which control the charging and discharging paths of the battery cells. Diodes and additional ideal switches (Switch 3 and 4) are used to direct current flow and prevent backflow, enhancing the system's reliability. The energy is delivered to a resistive load, and the output is monitored in real-time through Display blocks showing SOC values. The model operates with a discrete time step of 0.0005 seconds, making it suitable for high-frequency switching applications. Overall, the system effectively manages power distribution based on the state of charge, ensuring balanced usage of the battery cells.

SIMULATION RESULTS

At Charging Time -

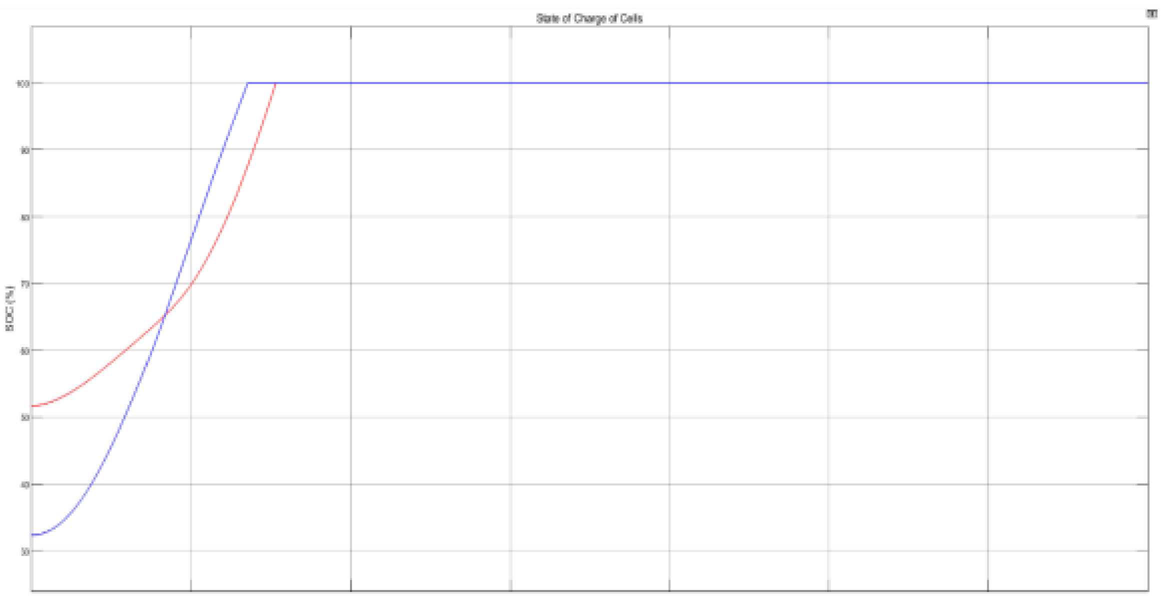

Fig.4 Charging Result

The graph illustrates the State of Charge (SOC) behavior of two battery cells over time within a controlled charging system. Initially, Cell 1 starts at a higher SOC of around 20%, while Cell 2 begins with a lower SOC of approximately 5%. As the simulation progresses, both cells experience an increase in SOC, with Cell 2 charging at a faster rate due to the SOC-based control strategy implemented in the system.

This control mechanism prioritizes the charging of the more depleted cell to ensure balanced energy levels between the two cells. Around the 15-second mark, both cells reach full charge (100% SOC), at which point their SOC values stabilize, indicating that the charging process has stopped or has been regulated to prevent overcharging.

The flat portion of the curves after this point confirms that the system has successfully balanced and fully charged both cells. Overall, the graph demonstrates that the SOC-based control strategy is functioning effectively, promoting optimal energy management and battery protection.

At Dis-Charging Time-

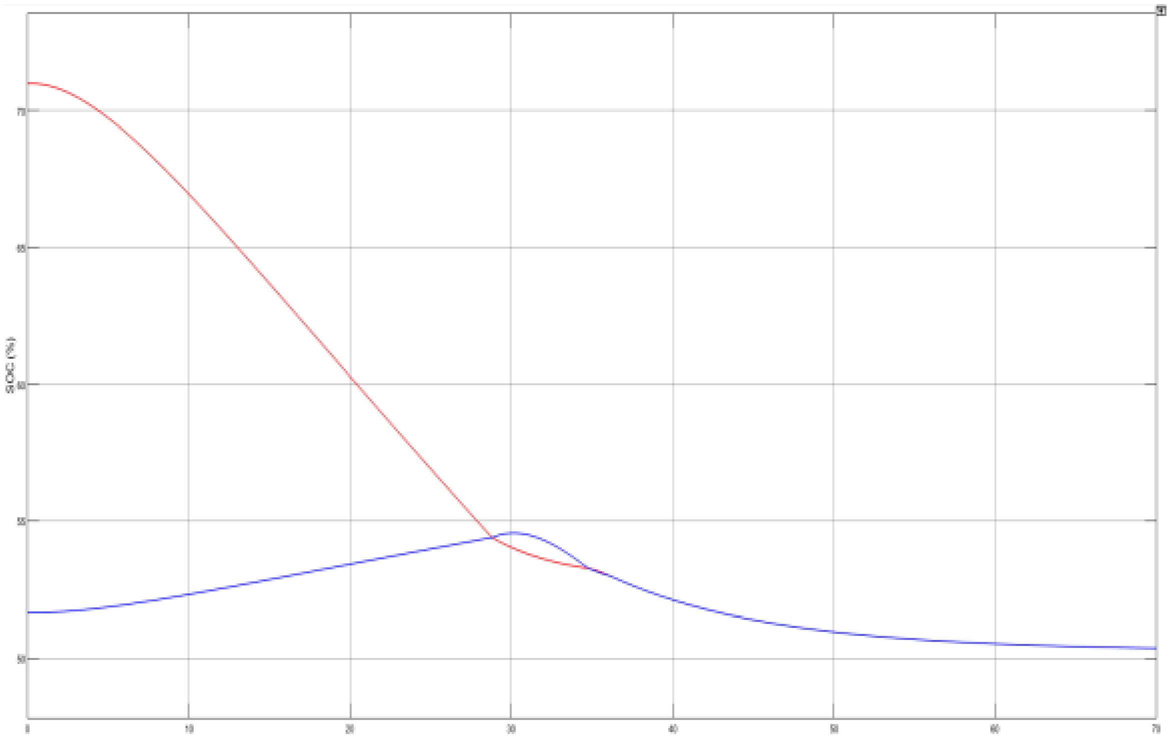

Fig. 5 Discharging Result

The graph depicts the discharging behaviour of two battery cells governed by a state-of-charge (SOC) based control strategy. At the beginning of the simulation, Cell 1 (red curve) is fully charged with an SOC of approximately 100%, whereas Cell 2 (blue curve) starts at a significantly lower SOC of around 15%. The control logic is designed to prioritize discharging from the cell with the higher SOC in order to protect and preserve the weaker cell. As a result, the system initially draws current predominantly from Cell 1, causing its SOC to decline steadily over time. During this phase, Cell 2 shows minimal change in SOC, even experiencing a slight increase initially, possibly due to reduced load or redistribution of current.

As the discharging process continues, Cell 1's SOC gradually decreases and approaches that of Cell 2. Around the 30-second mark, both cells reach similar SOC levels, indicating a crossover point. At this stage, the control logic adjusts the current flow, allowing Cell 2 to begin discharging more actively.

Following this transition, the blue curve for Cell 2 begins to drop more sharply, while the red curve for Cell 1 starts to flatten, indicating a reduced discharge rate. This balanced discharging continues for the remainder of the simulation, with both cells supplying power to the load in a more coordinated manner.

Overall, the graph demonstrates the effectiveness of the SOC-based control system in managing battery usage. By prioritizing the discharge of the more charged cell and gradually balancing the contribution from both cells, the system ensures optimized energy utilization and protection of the battery pack.

This approach not only extends the operational life of the cells but also maintains stability in power delivery throughout the discharging cycle.

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Hardware Result of Active Cell Balancing Technique

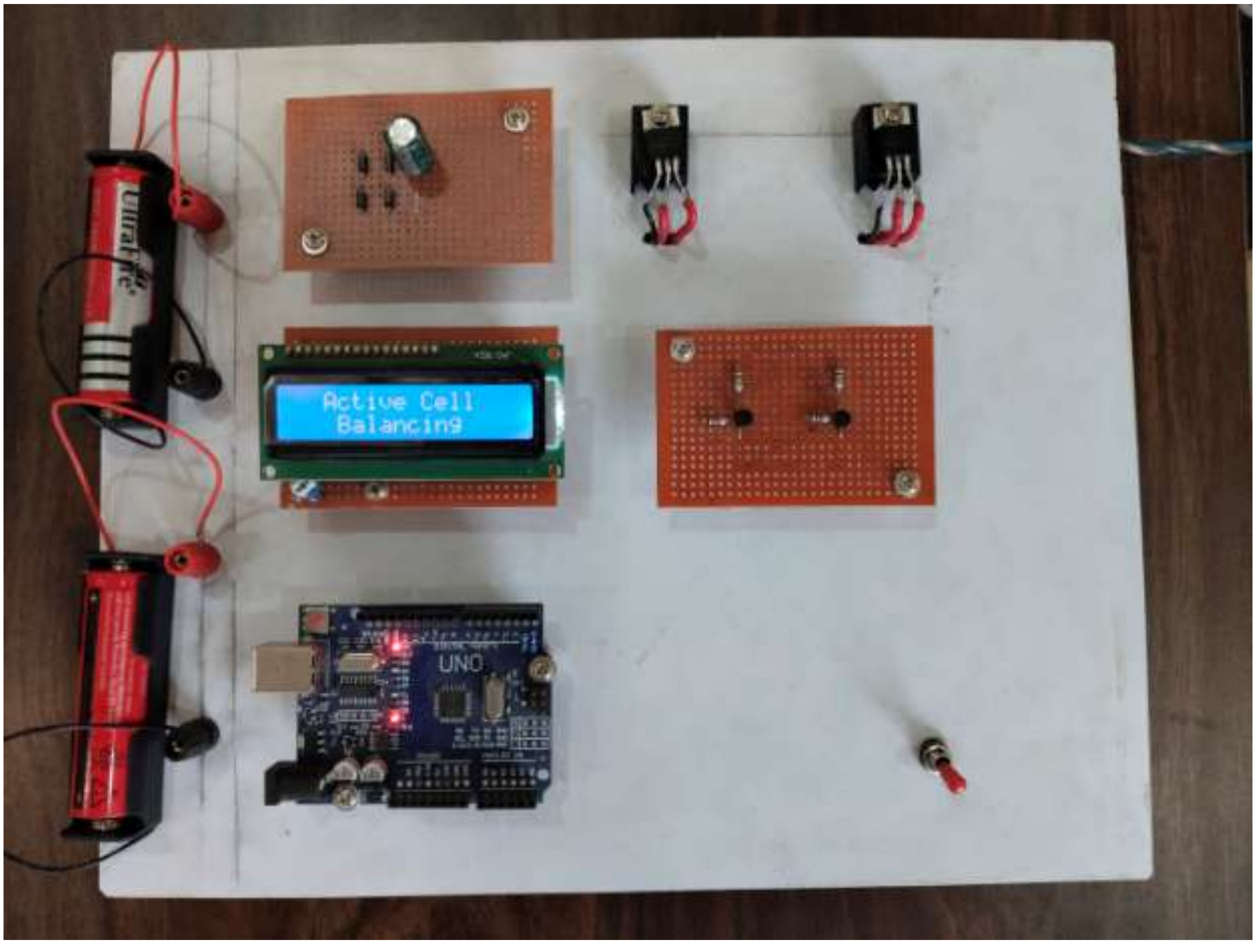

Fig. 6 Hardware of Active Cell Balancing

The setup includes two battery cells (placed in holders on the left side), an Arduino Uno microcontroller (bottom center), and various supporting electronic circuits mounted on perforated boards. The LCD display in the center shows the message "Active Cell Balancing", indicating that the system is monitoring and managing the charge levels of individual cells in real time. The system likely uses voltage sensing and control algorithms programmed into the Arduino to detect imbalance between the cells and trigger switching circuits (visible as MOSFETs or transistors on the top right) to actively transfer charge from a higher SOC cell to a lower one. Additional components such as resistors, capacitors, and possibly voltage dividers are used for sensing and filtering. A toggle switch on the bottom right is used to power the system on or off. This prototype demonstrates the implementation of an active balancing technique, which improves battery performance and lifespan by ensuring all cells maintain a similar charge level

CONCLUSION

Active cell balancing a vital technology for the efficient and reliable operation of electric vehicle (EV) battery systems. By redistributing energy between cells to equalize their charge levels, it addresses the challenges of cell imbalance, enhancing battery performance, safety, and longevity. Unlike passive balancing, active balancing minimizes energy losses Enhancing its suitability for high-performance electric vehicle applications. The technique ensures optimal energy utilization, extending driving range and preventing issues like overcharging and undercharging, which can degrade battery health. Additionally, it plays a critical role in thermal management, reducing the risk of overheating and improving overall system safety. While active balancing systems involve greater complexity and cost, ongoing Progress in circuit design, power electronics, and the integration of intelligent control systems are expected to make them more efficient and affordable. As EV technology evolves, active cell balancing will remain a cornerstone of advanced battery management, enabling the next generation of electric vehicles to achieve greater efficiency, sustainability, and reliability.

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